Germanium Nanoantennas for Plasmon-Enhanced Third Harmonic Generation in the Mid Infrared

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Recent advances in semiconductor film deposition allow for the growth of heavily-doped germanium with effective plasma frequencies above 60 THz, corresponding to wavelengths below 5 µm. This technology paves the way for mid-infrared nanoplasmonics with application in integrated telecommunication systems and enhanced molecular sensing in the so-called vibrational fingerprint spectral region [1].

In this work, we demonstrate that Ge antenna structures are also suitable for nonlinear optical processes such as third harmonic generation (THG) in the mid infrared [2], owing to the strong resonant enhancement. Sub-wavelength-confined light emitters are of high interest for experiments targeting single molecules or other isolated quantum systems [3].

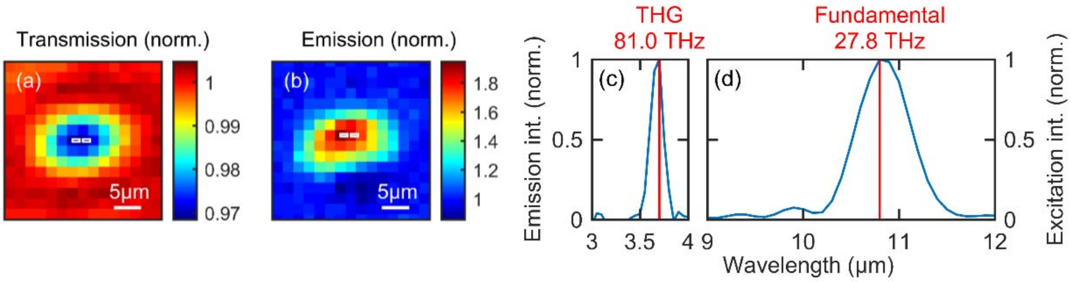

Fig. 1 (a) Linear transmission map of a 2.75-µm-long double rod antenna illuminated with a central wavelength of 10.8 µm including a sketch of the structure (white); (b) spatially resolved nonlinear emission after 6-µm-short-pass sapphire filter normalized to the silicon substrate background emission; (c) and (d) normalized THG and excitation intensity spectra, respectively.

Doped single-crystalline germanium films are grown via low-energy plasma enhanced chemical vapor deposition (LEPECVD) on intrinsic silicon substrates. Double-rod antenna structures are fabricated subsequently via electron beam lithography to be resonant at the fundamental excitation [4].

The optical system is driven by a Yb:KGW femtosecond laser equipped with optical parametric amplifiers. Intense few-cycle pulses tunable in the mid-infrared spectral range are obtained via difference frequency generation in GaSe. Excitation fields of up to 20 MV/cm are reached in the focus of a Cassegrain-Schwarzschild reflecting objective. A second objective images the antenna in transmission geometry. A mercury cadmium telluride (MCT) detector cooled by liquid nitrogen collects the emission while the sample is scanned through the confocal region. This allows addressing single antennas and mapping their linear and nonlinear response.

Fig. 1(a) shows the transmission image at the fundamental excitation wavelength (10.8 µm, Fig.1(c)) with the extinction due to the increased resonant scattering while Fig. 1(b) plots the corresponding THG emission at 3.7 µm wavelength (Fig. 1(d)). The nonlinearity is strongly enhanced at the antenna with respect to the substrate.

In conclusion, semiconductor plasmonic antennas enhance the nonlinear optical emission at the nanoscale with interesting perspectives in coherent ultrafast nearfield microscopy.

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